

# **To What Extent Can Increased Evapotranspiration Due to Groundwater Based Irrigation in the Great Plains of the United States Alter Regional Climate?**

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## **Overview**

Impacts of large scale land use changes on climate have become a significant focus of the global change community. For example an extensive field, air and satellite program, partly funded by NASA, has been undertaken to study the effects of deforestation and burning on climate within Amazonia (e.g., Jonquieres and Marenco, 1998), and studies of the Amazonia region indicate that changes in vegetation in the region have the potential to have significant regional and global impacts on climate (e.g., Matsueda, 1998). Studies have not been restricted to Amazonia and associated vegetative changes. As noted in a review paper by Giorgi and Mearns (1991), local climate impacts due to land use alteration induced by agricultural practices have been the focus of several theoretical and observational studies. With models of various degrees of complexity, Yan and Athes (1988), Mahfouf et al. (1987), Ookouchi et al. (1984), and Segal et al. (1988) investigated the possibility that sharp contrasts in surface vegetation characteristics, such as those that occur in the presence of large irrigated areas in semiarid regions, would generate strong horizontal gradients in surface heat fluxes. These could initiate mesoscale circulation similar to the seabreeze and trigger convective precipitation at the breeze front. More recently, areas where

large scale human disturbances have been mostly hydrologic, such as the mining of water in the Asian Aral Sea for irrigation, have also been the focus of extensive study (e.g., Small et al., 1999). The overriding goal of most of this research is to not only understand past human influence on climate, but also to predict the climatic impact of future land use changes.

The Great Plains region of the United States, and in particular the region bounded by Nebraska to the north and the Texas panhandle to the south, has since 1940 undergone the largest human induced hydrologic disturbance in North America. From 1940 to 1949, 7560 km<sup>2</sup> of land was placed under irrigation with groundwater from the Ogallala aquifer (Figure 1). By 1980, over 60000 km<sup>2</sup> of land was being irrigated by the Ogallala aquifer. Corn is the dominant crop in these irrigated lands, but other water intensive crops including cotton and sorghum are also grown. The use of irrigation water in the Great Plains, has not only transformed the former dust bowl lands of the 1930s into high yield acreage, it has also significantly altered the hydrologic cycle in the region. In the 1990s, about  $2 \times 10^{10}$  m<sup>3</sup> of groundwater is used annually for irrigation and is made available for evapotranspiration. The use of irrigation water roughly doubles the potential evapotranspiration of farmland in the southern Great Plains. The Ogallala aquifer covers a region of over 445,000 km<sup>2</sup>; and while the 1980s and 1990s have seen increased efforts at water conservation in the region and a slight decline in water demand, the potential exists for this aquifer to be associated with over  $1 \times 10^{11}$  m<sup>3</sup> of annual irrigation water. Barnston and Schickedanz (1984) carried out a statistical analysis of precipitation and water use data over the Texas Panhandle portion of the Great Plains. They found an increase in precipitation associated with irrigation of roughly 25% over and near irrigated areas. We propose to greatly expand on the study of Barnston and Schickedanz (1984) and examine the extent to which large human-induced transfer of groundwater (past, present and future) into the atmosphere influences climate of the entire Great Plains and neighboring regions to the east.

### **Available Data and Models for Analysis**

Because the advent of groundwater based irrigation in the region is relatively recent and because of the agricultural importance of the region (\$20,000,000,000 in crops grown in 1990), there are extensive existing data for analysis as well as existing regional circulation models that can be modified for the purposes of this study. An excellent precipitation network has been in existence for decades in the region, and data are readily available on both daily precipitation and rainfall intensity. Historical meteorological data on wind speed,

land surface humidity and atmospheric pressure are also available and will allow us to look at overall variations in climate and weather. Advanced Very High Resolution Radi-ometer (AVHRR) imagery, available since 1982, will allow us detailed (1 km<sup>2</sup>), frequent (biweekly) images of agri-cultural land use. Repeat Landsat images have been made since 1972 and the relatively inexpensive MSS data available until 1982 will allow us collaborative information on land use over space and time. Groundwater water level data have been extensively collected by the U.S. Geological Survey since the 1950s and by the 1980s included over 1000 wells in the region. Land-atmosphere water and energy exchanges for the region have been the focus of the GEWEX (Global Energy and Water Exchange) program in the 1990s. Regional (mesoscale) climate models are available and appropriate for studying problems of climate change, and the potential links between climate change and human-induced environmental changes. For example, a regional scale circulation model for a portion of the Great Plains was developed by Mearns et al. (1995a, 1995b), and the Great Plains were the focus of a general circula-tion model study (Atlas et al., 1993). Our study is highly integrative in nature and will depend heavily on both the recent research of others and historical physical and satellite data. The extensive previous work and associated hy-drologic, vegetative and meteorological data will allow us to examine the climatic and hydrologic impact of irrigation in this large region with excellent spatial and temporal detail.

## **References**

- \*Atlas, R. W., and N. Terry, The effect of SST and soil moisture anomalies on GLA model simulations of the 1988 U.S. summer drought, *Journal of Climate*, 6 (11), 2034-2048, 1993.
- \*Barnston, A. G., and P. T. Schickedanz, The effect of irrigation on warm season precipitation in the southern Great Plains *J. Climate Appl. Met*, 23, 865-888, 1984.
- \*Jonquieres I., and A. Marengo, Redistribution by deep convection and long-range transport of CO and CH<sub>4</sub> emissions from the Amazon basin, as observed by the airborne campaign TROPOZ II during the wet season, *J Geophys. Res.*, 103: (D15) 19075-19091, 1998.
- \*Matsueda, H., Inoue, H.Y., and Y. Sawa, Carbon monoxide in the upper troposphere over the western Pacific between 1993 and 1996, *J Geophys Res.*, 103 (D15), 19093-19110, 1998.
- \*Mahfouf, J. F., E. Richard, and P. Mascart, The influence of soil and vegetation on the development of mesoscale circulations, *J. Clim. Appl. Meteorol.*, 26, 1483-1495, 1987.

- \*Mearns, L. O., F. Giorgi, L. McDaniel, and C. Shields, Analysis of daily variability of precipitation in a nested regional climate model- comparison with observations and doubled CO2 results, *Global and Planetary Change*, 10: (1-4), 55-78, 1995a.
- \*Mearns, L. O., F. Giorgi, and L. McDaniel, Analysis of variability and diurnal range of daily temperature in a nested regional climate model-comparison with observations and doubled CO2 results, *Clim. Dynam.*, 11: (4), 193-209, 1995b.
- \*Ookouchi, Y., M. Segal, R. C. Kessler and R. A. Pielke, Evaluation of soil moisture effects on the generation and modification of mesoscale circulations, *Mon. Weather Rev.*, 112, 2281-2292, 1984.
- \*Segal, M., R. Avissar, M.C. McCumber, and R. A. Pielke, Evaluation of vegetation effects on the generation and modification of mesoscale circulations, *J. Atmos. Sci.*, 45, 2268-2292, 1988.
- \*Small, E.E., F. Giorgi , and L. Cirbus Sloan, Regional climate model simulation of precipitation in central Asia: Mean and interannual variability, in press, *Jour. Geophys. Research*, 1999.
- \*Yan, H., and R. A. Anthes, The effect of variation in surface moisture on mesoscale circulations, *Mon. Weather Rev.*, 116, 192-208, 1988.

Figure 1. Extent of the Ogallala aquifer and water level declines in the aquifer associated with irrigation, 1940-1980. Declines are a semi-quantitative indicator of cumulative irrigation induced evapotranspiration in the region. Yellow region while not intensely dewatered, has also been subject to extensive irrigation. Center circle represents an area of 250,000 km<sup>2</sup> for reference. Modified from Dugan and Cox (1994).

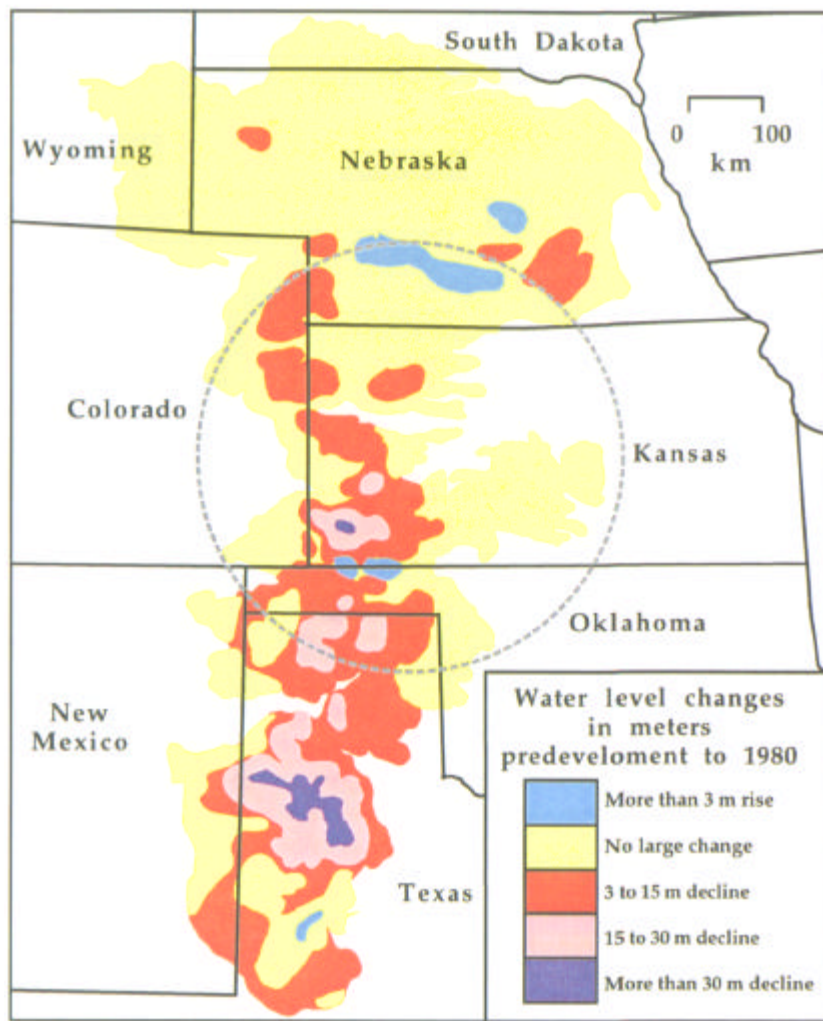


Figure 2. Land cover in the mid-continent of the U.S. Map has 1-km nominal spatial resolution, and is based on 1-km AVHRR data spanning April 1992 through March 1993. Massive dark tan area denotes region of irrigated farm land in the Great Plains. Image from US Geological Survey.

